LEACHATE TREATMENT USING SUBSURFACE FLOW AND FREE WATER SURFACE CONSTRUCTED WETLAND SYSTEMS

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This work is dedicated to my beloved family members, especially to abah (Kamarudzaman Hj. Abd. Rahim), mak (Saodah Hj. Abd. Karim), my bothers and sisters (Mohd. Suffian, Ainul Zakiah, Ahmad Zaki, Kamaliah and Atiqah). Thanks for all your love and support!

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ABSTRACT

The sanitary landfill plays a most important role in the framework of solid waste disposal. Discharge of leachate into the environment constitutes the major environmental concern associated with sanitary landfill and need to prevent. Based on previous study, constructed wetland system has high efficiency in treating landfill leachate with low operating and maintenance cost. A combination system utilizing a subsurface flow (SSF) wetland followed by a free water surface (FWS) wetland was studied to treat landfill leachate. In this study, *Limnocharis flava* and *Eichhornia crassipes* were used as aquatic plants in wetland system. SSF and FWS constructed wetland systems were arranged in series and operated for around 3 weeks with hydraulic loading rate (HLR) (0.13 m/cycle/day). Two lab scale systems of constructed wetlands were used in the experiments. Performance of SSF-FWS constructed wetland was evaluated with comparison to a Control system (unplanted). The result demonstrated that a combination system utilizing a SSF-FWS constructed wetland systems have shown higher performance in treating leachate landfill. The result demonstrated that the removal efficiency of pollutants in leachate using *Limnocharis flava* and *Eichhornia crassipes* in SSF-FWS constructed wetlands were NH_4-N (93.1%), NO_3-N (96.4%), PO_4^{3-} (95.9%), Fe (99.5%) and Mn (97.7%). Removal efficiency of SS and turbidity were achieved 87.3% and 99.6%, respectively. *Limnocharis flava* had higher capacity to accumulate heavy metals (Fe and Mn) in leachate constituents compared than *Eichhornia crassipes*. From the study, it shows that Fe and Mn uptake is more significant in roots compare to leaves. This study concludes that SSF-FWS constructed wetlands can increase the performance of nutrient and heavy metal removal and also enhance leachate water quality.

ABSTRAK

Tapak pelupusan sampah memainkan peranan penting dalam rangka kerja pelupusan sisa pepejal. Pelepasan air larut lesap ke alam sekitar menimbulkan kebimbangan yang tinggi terhadap alam sekitar berkaitan dengan tapak pelupusan sampah dan keadaan ini perlu dielakkan. Berdasarkan kajian yang dijalankan sebelum ini, sistem tanah bencah yang dirangka menunjukkan tahap efisyen yang tinggi dalam mengolah air larut lesap dengan kos operasi dan penyelenggaraan yang murah. Gabungan sistem menggunakan tanah bencah buatan aliran subpermukaan (SSF) dan diikuti dengan tanah bencah buatan aliran permukaan bebas (FWS) telah dikaji untuk mengolah air larut lesap. Dalam kajian ini, *Limnocharis flava* dan *Eichhornia crassipes* telah digunakan sebagai tumbuhan akuatik dalam sistem tanah bencah. Sistem tanah bencah buatan SSF dan FWS disusun secara bersiri dan beroperasi dalam jangka masa 3 minggu dengan kadar masukan hidraulik (0.13 m/kitaran/hari). Dua sistem tanah bencah buatan berskala makmal telah digunakan di dalam kajian ini. Prestasi sistem tanah bencah buatan SSF-FWS ini telah dinilai dan diperbandingkan dengan sistem kawalan iaitu tanpa tumbuhan. Keputusan yang diperolehi menunjukkan bahawa gabungan sistem tanah bencah buatan SSF dan FWS menunjukkan prestasi yang lebih baik dalam mengolah air larut lesap. Keputusan menunjukkan bahawa kadar penyingkiran bahan pencemar dalam air larut lesap menggunakan *Limnocharis flava* dan *Eichhornia crassipes* dalam sistem tanah bencah buatan SSF-FWS adalah NH_4-N (93.1%), NO_3-N (96.4%), PO_4^{3-} (95.9%), Fe (99.5%) and Mn (97.7%). Tahap penyingkiran yang efisien bagi SS dan kekeruhan pula dicapai sebanyak 87.3% dan 99.6%. *Limnocharis flava* mempunyai kapasiti yang lebih tinggi untuk mengumpul logam berat (Fe and Mn) dalam juzuk air larut lesap jika dibandingkan dengan *Eichhornia crassipes*. Daripada kajian yang dijalankan, ia menunjukkan bahawa pengambilan Fe and Mn adalah lebih ketara di akar berbanding dengan daun. Kajian ini dapat memberi kesimpulan bahawa sistem tanah bencah buatan SSF-FWS boleh meningkatkan prestasi penyingkiran kandungan nutrien and logam berat dan juga meningkatkan kualiti dalam air larut lesap.

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LIST OF SYMBOLS AND ABREVIATIONS

BOD	-	Biochemical Oxygen Demand
cm/day	-	Centimeter per day
CAP	-	Consumers Association of Penang
Ca^{2-}	-	Calcium
$CaCO_3$	-	Calcium carbonate
C/C_O	-	Present concentration over initial concentration
Cl	-	Clorine
Cl_2	-	Chlorine gas
Cd	-	Cadmium
Cr	-	Chromium
COD	-	Chemical Oxygen Demand
CWs	-	Constructed wetland
Fe	-	Ferum
FWS	-	Free Water Surface
HCO_3^-	-	Bicarbonate
HF-SSF	-	Horizontal Subsurface Flow
HLR	-	Hydraulic Loading Rate
HRT	-	Hydraulic Retention Time
IUCN	-	International Union for the Conservation of Nature
kg	-	Kilogram
kg/m^3	-	Kilogram per meter cube
m	-	Meter
mm	-	Millimeter
m/day	-	Meter per day
mg/g	-	Milligram per gram

mg/L	-	Milligram per liter
mL/s	-	Milliliter per second
Mg^{2+}	-	Magnesium
MLVSS	-	Mix liquor Volatile Suspended Solid
Mn	-	Manganese
N_2	-	Nitrogen gas
N_2O	-	Nitrogen Oxides
NH_4^+	-	Ammonia
NH_4-N	-	Ammonia Nitrogen
NO_2^-	-	Nitrite
NO_3^-	-	Nitrate
NO_2 -N	-	Nitrite Nitrogen
NO_3 -N	-	Nitrate Nitrogen
P	-	Phosphorus
PO_4^{3-}	-	Orthophosphate
SO_4^-	-	Sulfate
SSF	-	Subsurface Flow
SSF-FWS	-	Combine Subsurface Flow and Free Water Surface System
SS	-	Suspended Solid
TIN	-	Total Inorganic Carbon
TKN	-	Total Kjeldahl Nitrogen
TN	-	Total Nitrogen
TP	-	Total Phosphorus
TOC	-	Total Organic Carbon
TSS	-	Total Suspended Solid
VF	-	Vertical Flow
VF-SSF	-	Vertical Subsurface Flow
VFA	-	Volatile Fatty Acid
VOC	-	Volatile Organic Carbon
RBC	-	Rotating Biological Reactor
Zn	-	Zinc
µg/g	-	Microgram per gram
%	-	Percent
˚C	-	Degrees Celsius

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Solid waste disposal creates a problem primarily in highly populated areas. In general, the more concentrated the population, the greater the problem becomes, although some very populated areas have developed creative solutions to minimize the problem. Various estimates have been made of the quantity of solid waste generated and collected per person per day. Malaysia, like most of the developing countries, is facing an increase of the generation of waste and accompanying problems with the disposal of this waste. Municipal, industrial, agricultural, and urban activities produce huge amounts of wastes which require permanent disposal. Overall, the local communities generate 16,000 tonnes of domestic waste per day and the amounts per capita vary from 0.45 to 1.44 kg per day depending on the economic status of the areas concerned. On average, waste generation in Malaysia is about 1 kg per capita per day (Lina, 2004).

There are different alternatives to reduce, treat and dispose the solid wastes. In many developing countries including Malaysia, sanitary landfills have been the most popular method of municipal solid waste disposal. There are 230 official dumping sites in Malaysia, the majority of which are crude landfills, with only 10% providing leachate treatment ponds and gas ventilation systems and with most having no control mechanisms and supervision (Zaman, 1992). However, the amount of waste produced rapidly increases; space for permanent disposal becomes crucial. Since the production of solid waste is increasing much more rapidly than it degrades, land space for disposal has become more difficult and expensive to attain. Incineration of solid waste can be used but this is expensive and the emissions are of health concern. This is why landfills remain the major solid waste disposal option for most countries.

In conjunction with the increasing number of sanitary landfills, leachate treatment has become a major environmental issue, especially with regulatory agencies and environmentalists. The treatment of landfill leachates is of concern because they have the potential to degrade the environment. Leachates are a potential hazardous waste from landfill sites. Malaysian solid wastes contain very high organic waste and consequently high moisture content and bulk density of above 200 kg/m^3. A recent study conducted in Kuala Lumpur has revealed that the amount of organic wastes for residential area range from 62 to 72% (CAP, 2001). Therefore, leachate production may arise because most of solid wastes contain high moisture content and organic matter.

Most organic matter contained in the solid wastes is biodegradable and can be broken down into simpler compounds by anaerobic and aerobic microorganisms, leading to the formation of gas and leachate. Leachate is defined as liquid that has percolated through solid waste and has extracted dissolved or suspended materials from it. It arises from the biochemical and physical breakdown of waste (Lu *et al.*, 1985). Landfill leachate characteristics vary depending on the operation type of the landfill and the age of the landfill. Leachate initially is a high-strength wastewater, contains high concentration of organic matter, inorganic matter and heavy metal (Qasim and Chiang, 1994). The main environmental aspects of leachate are the impacts on surface water quality and groundwater quality, because leachate may migrate from the refuse and contaminate the surface waters and groundwater. If not dealt properly its can affecting aquatic ecosystems, human health problems and effect the environment. It is important that leachates are treated and contained to prevent these occurrences.

Therefore, the treatment of leachates by natural systems seems to be environmentally sustainable for treatment of many constituents. Constructed wetlands have proven very effective technology for the treatment of variety of wastewaters. Constructed wetlands are increasingly being employed to treat landfill leachate, and the use of natural systems in waste management seems to be gaining in popularity as a result of their sustainability and cost savings. Wetland has been shown to improve leachate quality through processes that include microbial mediated transformations, biotic uptake of organic chemicals and nutrients, precipitation, complexation and adsorption reactions (Kadlec and Knight, 1996; Brix, 1997; Mutamoottil *et al*., 1999). A thorough understanding of these mechanisms is required before a constructed wetland system can be developed that can provide successful, long-term treatment of landfill leachate on a large scale.

The environmental benefit treatment of leachate in a constructed wetland include; decreased energy consumption by using natural processes rather than conventional, electrically driven wastewater-treatment processes; efficiently removed many pollutants from wastewater and also enhance the environment by providing a habitat for vegetation, fish and other wildlife (Jin *et al.*, 2003). Studies of the long-term use of wetlands for leachate treatment have demonstrated significant economic advantages, mainly through lowered construction, transportation and operation costs (Kadley and Knight, 1996).

1.2 Problem Statement

Landfill leachate with its variable and complex characteristics poses a well established threat to the environment. Leachate is often quite varies in water quality but generally has very high concentrations of Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), and ammonia content, with high COD and BOD ratio and the presence of heavy metals ions present unique difficulties treatment of landfill leachate (Aeslina, 2004). Landfill leachates will cause environmental problems if it is not properly handled. Increase in landfill leachate creates challenges for those seeking cost effective treatment methods to process this wastewater. Enhancement of the environmental quality through the minimization of the leachate problem should therefore be the major objective of good landfill management. The need to control and manage landfill leachate has resulted in various treatment alternatives which include both biological and physical-chemical processes (Ho *et al.*, 1974; Lu *et al.*, 1984; Qasim and Chiang, 1994).

Usually several physical-chemical wastewater treatment technologies are used to treat the leachate. These physical-chemical approaches to leachate treatment are undesirable since the costs of operation and maintenance are high, and labors and services are required even after landfill site closure. Some of these processes even require extensive pretreatment process (Britz, 1995). However, these types of treatment systems were hardly comply with the Environmental Quality Act, 1974.

For a small community with limited funds for expanding or updating wastewater treatment plants, constructed wetlands are an attractive option. Rural municipalities have access to adequate inexpensive land, and wetlands blend into a natural landscape setting. Once the wetlands are designed and constructed, annual maintenance costs are low. Municipalities in general have small budgets and they normally face a lack of adequately trained staff. Investment into sustainable reclamation of landfill sites could be more favourable and justifiable from an economic, environmental and also human-resources point of view. In addition, wetlands add aesthetic value, and provide wildlife habitat and recreation opportunities (Renee, 2001).

Therefore, constructed wetland was developed as an alternative method to treat leachate since constructed wetland has low cost of construction and maintenance. Constructed wetlands have great potential as a clean-up technology for a variety of wastewaters. Constructed wetlands have proven to be a very effective method for the treatment of municipal wastewater. For example, agricultural wastewater, industrial wastewater, storm water runoff, landfill leachate and airport runoff are all good candidates for remediation using constructed wetlands (Renee, 2001; Lin *et al.*, 2005). The treatment of landfill leachate is one particular application for which constructed wetlands have been used widely (Crites, 2005). In numerous studies, wetland systems have shown great potential in removal of heavy metals in landfill leachate (Lu *et al*., 1984; Qasim and Chiang, 1994; Renee *et al*., 2001; Nancy, 2004). Due to its high rate of the biological activities, the wetland can transform common pollutants into harmless byproducts and essential nutrients (Kadlec and Knight, 1996). In this research, a combination system utilizing a subsurface flow (SSF) wetland followed by a free water surface (FWS) wetland was studied to treat landfill leachates.

1.3 Objective of the Study

The objectives of the study are:

(i) To investigate the performance of the SSF-FWS constructed wetland system in treating landfill leachate.

(ii) To examine the effect of the SSF-FWS constructed wetland system on leachate quality for Suspended solid (SS), Turbidity, Ammonia Nitrogen (NH_4-N), Nitrate Nitrogen (NO_3–N), Orthophosphate (PO_4^{3-}) and heavy metal (Ferum (Fe) and Manganese (Mn)) removal.

(iii) To examine the amount of heavy metal taken off by roots and leaves of the wetland plants for SSF and FWS constructed wetland system.

1.4 Scope of the Study

The scope of study includes set-up a two-stage lab-scaled system comprised of a SSF and FWS constructed wetland to treat landfill leachate. The leachates were collected from Pasir Gudang Municipal Landfill, Pasir Gudang, Johor and initial water quality of the leachates were analysed. The efficiency of leachate treatment was evaluated in terms of water quality parameters SS, turbidity, NH_4-N, NO_3-N, PO_4^{3-} and heavy metal (Fe and Mn) analysis. The experiment was carried out for duration of 18 days. The amount of heavy metal (Fe and Mn) uptake by plants was determined by analysis the heavy metal concentration in plant leaves and roots. The vegetation species used are *Limnocharis flava* for SSF and *Eichhornia crassipes* for FWS constructed wetland. The experiment was carried out at Environmental Engineering Laboratory, Faculty of Civil Engineering, Universiti Teknologi Malaysia

1.5 Importance of the Study

The use of constructed wetlands to treat water pollution is relatively new development in Malaysia. The recently completed Putrajaya Constructed Wetland and Lake system, which is designed to treat stormwater runoff. The abundance of wetland plant species and good conditions for plant growth in Malaysia provided an ideas environment for introducing constructed wetlands for the treatment of leachate. The potential to expand the use of constructed wetlands to the treatment of leachates beyond the more general treatment of wastewaters is relevant in today's context. It also an environmental friendly approach to remove pollutants from leachate. Many studies have been conducted for leachate treatment in wastewater treatment using single type of constructed wetlands, whether SSF or FWS system. Nevertheless, the study of combine system of constructed wetland (SSF-FWS) for leachate treatment has not been investigated in Malaysia.

Therefore, in this research, a combination system utilizing a SSF wetland followed by a FWS wetland were studied to treat landfill leachates and by incorporating local component and expertise. In term of removal efficiency, the percentage of removal under SSF-FWS constructed wetland systems should be much better to enhance leachate quality compare than one-single type constructed wetland system. Beside that, the performance of SSF-FWS constructed wetland system hope strongly supports the use of wetlands as efficient, low cost alternatives to conventional treatment of landfill leachate.

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